

# HIGH PERFORMANCE PSEUDO-DUCTILE COMPOSITES

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## ABSTRACT

Current composites normally fail suddenly and catastrophically, which is an undesirable characteristic for many applications. This paper describes work as part of the High Performance Ductile Composite Technology programme (HiPerDuCT) to overcome this key limitation by introducing pseudo-ductility into the failure process.

## 1 INTRODUCTION

Composite materials have excellent specific strength and stiffness, but a major drawback is their lack of ductility. The HiPerDuCT programme is a collaboration between the University of Bristol and Imperial College to address this challenge by developing new materials and architectures that give a more gradual failure.

Three fundamental mechanisms are considered in this paper which enable pseudo-ductility under tensile loading: fibre reorientation, hybridisation, and mode II interfacial slip in discontinuous composites. Pseudo-ductile strain has been proposed as a key measure to assess progress, defined as the difference between the final failure strain, and the elastic strain at the same stress, Fig. 1.

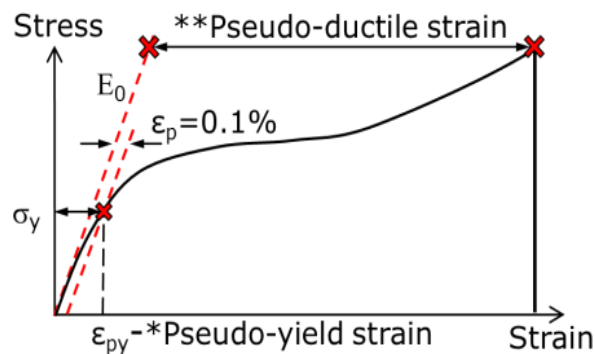


Figure 1: Definition of pseudo-ductile strains

## 2 DUCTILITY VIA FIBRE RE-ORIENTATION

It has been successfully demonstrated that using Skyflex carbon/epoxy plies of only 0.03 mm thickness, matrix cracking and delamination can be completely suppressed in angle-ply laminates, allowing the fibres to rotate under tensile loading, creating additional strain and pseudo-ductility [1]. Angle plies of ( $\pm 45$ ) layup can produce strains of over 20% and necking behaviour despite the brittle nature of the matrix (see Fig. 2). There is a trade-off between the stresses and strains that can be achieved

depending on the angle, and this has been investigated in modelling studies [2]. A good balance of properties has been achieved for example with thin ply ( $\pm 25$ ) carbon/epoxy laminates that gave a pseudo-ductile strain of 1.23% and a maximum stress of 927 MPa, Fig. 3 [1].

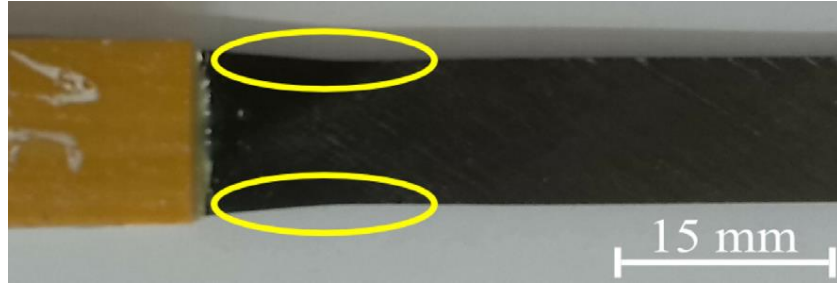


Figure 2: Necking of ( $\pm 45$ ) thin carbon/epoxy angle ply specimen

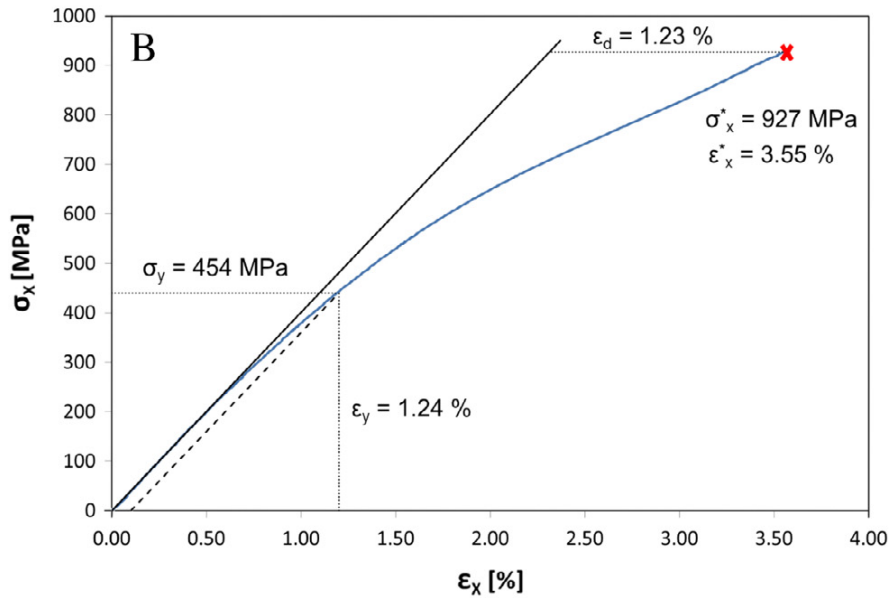


Figure 3: Pseudo-ductile response of thin ply ( $\pm 25$ ) carbon/epoxy laminate

### 3 DUCTILITY VIA FRAGMENTATION IN THIN-PLY HYBRIDS

Suppressing delamination in hybrid laminates can also be achieved by using thin plies [3]. Modelling has shown that both the relative and absolute thickness of the plies are important [4-6]. Damage mode maps can be produced, (see Fig. 4) and with the correct thicknesses, premature brittle failure of the whole hybrid plate and catastrophic delamination can be avoided. This leads to the new failure mechanisms of fragmentation of the stiffer ply, and stable pull-out of the fragments, producing a pseudo-ductile stress-strain response. There is a trade-off between pseudo-ductility and yield stress. Fig. 5 shows a typical response for two 22 g/m<sup>2</sup> plies of high strength TR30 carbon sandwiched between two 190 g/m<sup>2</sup> S-glass epoxy plies. A range of different glass-carbon hybrid configurations has been evaluated, and pseudo-ductile strains of up to 2.66% have been obtained with a plateau stress of 520 MPa, or 0.86% pseudo-ductile strain with a plateau stress of over 1300 MPa.

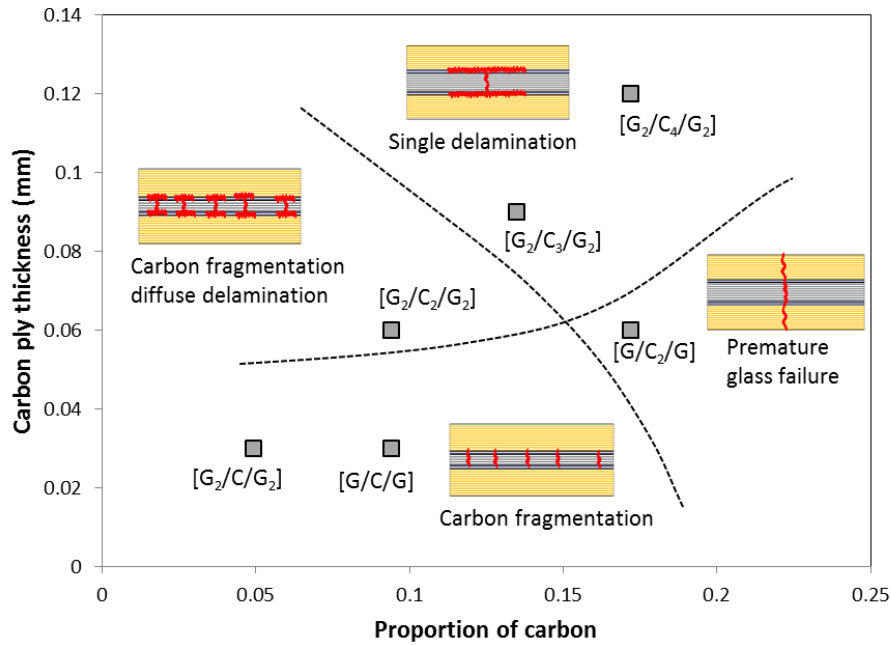


Figure 4: Damage mode map for E glass/thin carbon hybrid composite [4]

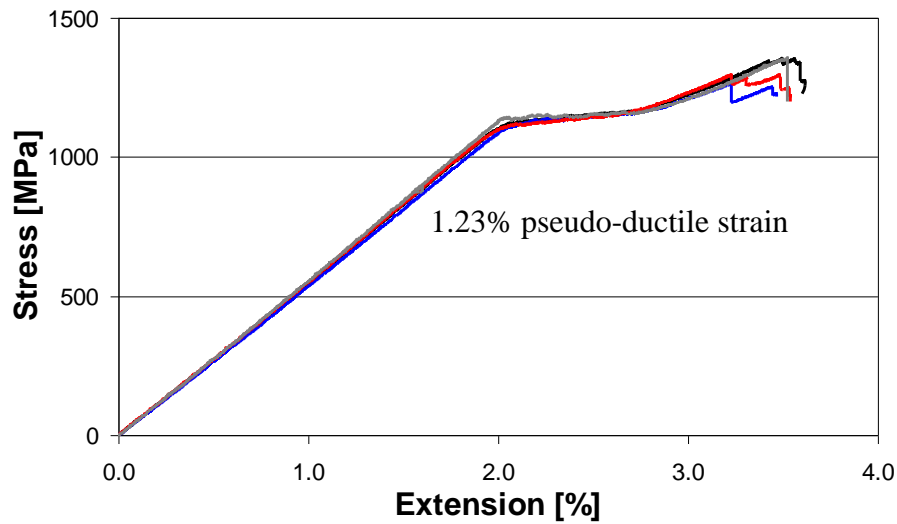


Figure 5: Pseudo-ductile response of S-glass/high strength carbon hybrid

#### 4 DUCTILITY VIA FRAGMENTATION IN THIN ANGLE PLIES WITH 0° PLIES

The two previous mechanisms can be combined by replacing the lower modulus glass plies with carbon fibre angle plies [7]. This allows the fragmentation mechanism exhibited by the unidirectional hybrid composites to occur in the 0° plies together with the fibre rotation of the angle plies. For example  $[\pm 26_s/0]_s$  laminates of Skyflex thin carbon/epoxy gave the response shown in Fig. 6, with a pseudo-ductile strain of 2.2%.

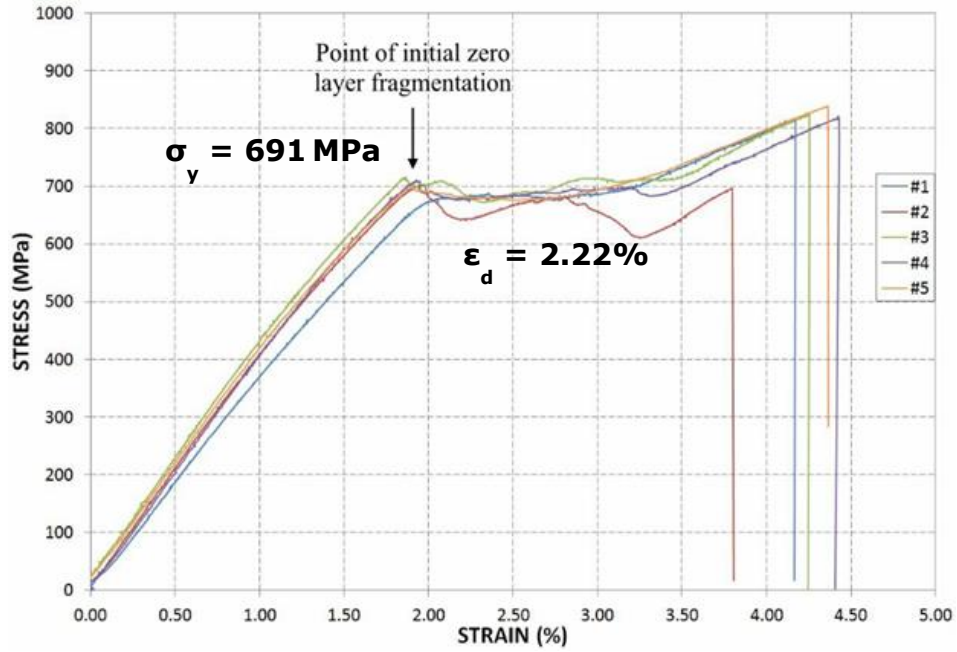


Figure 6: Pseudo-ductile response of  $[\pm 26_5/0]_S$  laminate

## 5 DUCTILITY VIA INTERFACIAL SLIP IN DISCONTINUOUS LAMINATES

Another mechanism for pseudo-ductility is slip between discontinuous plies at the interface. This has been demonstrated in model systems of discontinuous carbon/epoxy prepreg where the plies have been cut through the thickness prior to layup. The effect of ply thickness, cut spacing and alignment on response have been investigated both numerically and experimentally [8]. For example specimens of IM7/8552 carbon/epoxy with 0.25 mm thick discontinuous ply blocks (0.125 mm for surface plies) and overlap length of about 8 mm were tested, (see Fig. 7.). Significant non-linearity was obtained, providing a clear indication of overloading, with a modest pseudo-ductile strain of 0.25%.

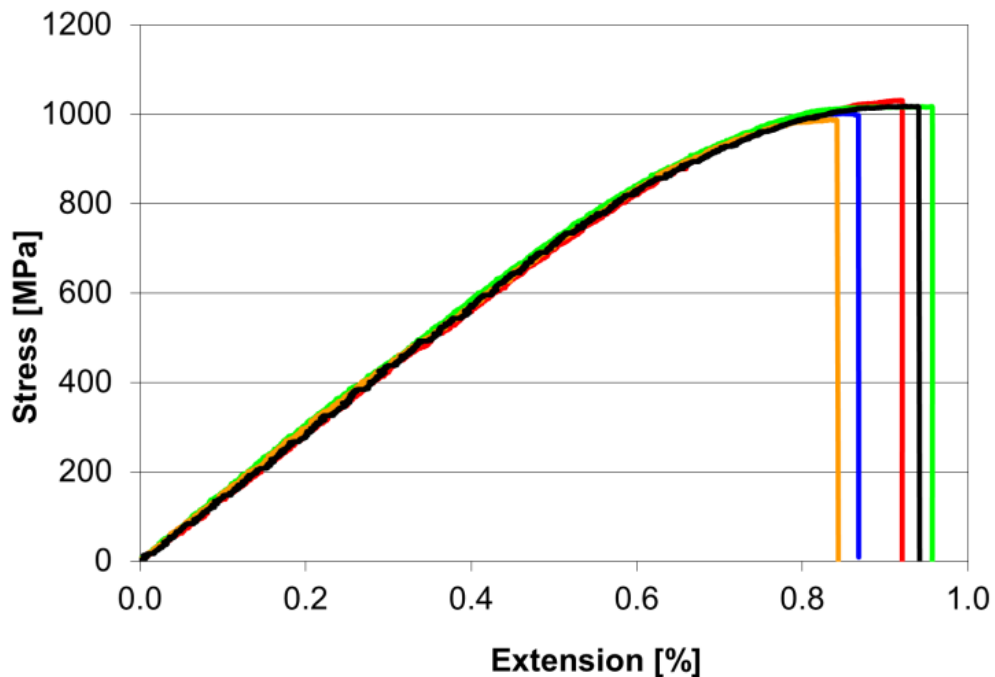


Fig. 7. Non-linear response of discontinuous carbon/epoxy laminate

## 6 CONCLUSIONS

A number of different mechanisms have been demonstrated by which the sudden catastrophic failure of conventional composites in tension can be overcome, and a pseudo-ductile, gradual failure achieved. Using very thin plies can suppress matrix cracking and delamination, allowing fibre rotation and large strains to be obtained in angle-ply laminates. Thin ply hybrids can fail gradually by in-situ ply fragmentation. These mechanisms can be combined to produce laminates that demonstrate significant pseudo-ductile strain by both fragmentation and rotation. More limited pseudo-ductility has also been demonstrated in model systems of discontinuous carbon/epoxy plies. These results open up new possibilities for creating high performance composites that fail in a more gradual manner.

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